

**\*\*Volume Title\*\***

*ASP Conference Series, Vol. **\*\*Volume Number\*\****

**\*\*Author\*\***

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## **MIS: a MIRIAD Interferometry Singledish toolkit**

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### **Abstract.**

Building on the “drPACS” contribution at ADASS XX of a simple Unix pipeline infrastructure, we implemented a pipeline toolkit using the package MIRIAD to combine Interferometric and Single Dish data (MIS). This was prompted by our observations made with the Combined Array For Research in Millimeter-wave Astronomy (CARMA) interferometer of the star-forming region NGC 1333, a large survey highlighting the new 23-element and singledish observing modes. The project consists of 20 CARMA datasets each containing interferometric as well as simultaneously obtained single dish data, for 3 molecular spectral lines and continuum, in 527 different pointings, covering an area of about 8 by 11 arcminutes. A small group of collaborators then shared this toolkit and their parameters via CVS, and scripts were developed to ensure uniform data reduction across the group. The pipeline was run end-to-end each night as new observations were obtained, producing maps that contained all the data to date. We will show examples of the scripts and data products. This approach could serve as a model for repeated calibration and mapping of large mixed-mode correlation datasets from ALMA.

## **1. Introduction**

In a previous paper (Teuben 2011) a very simple and easy to use Unix pipeline toolkit was introduced, dubbed “drPACS”. The intent of this toolkit was to provide an infrastructure that made it not only easy to define a set of steps to reduce a dataset, but also to apply these steps to many similar datasets. A set of parameters would then control the pipeline. This could be applied to observational data as well as theoretical data, and has a very low buy-in cost (cf. Mandel et al. (2001)) and works on pretty much any out-of-the-box (Unix) workstation. The simplicity of the pipeline also encourages the user to experiment with parameter settings and, in what can often be a very complex flow of data morphing, get a better feeling for the robustness of the results.

## **2. The CARMA-23 Data**

In January 2011, CARMA commissioned its new “CARMA-23” mode which correlates all baselines from the 23-element array using the new CARMA spectral correlator. The correlator was commissioned in 2009 for 15-element 8-GHz bandwidth operations, and new FPGA programming was later implemented to allow 23-element operation with 4-GHz bandwidth. CARMA is a heterogeneous array consisting of six 10.4-m, nine 6.1-m, and eight 3.5-m antennas. The heterogeneous nature of the array and 253 baselines

allow for a large dynamic range in sensitivity to spatial scales and excellent imaging fidelity.

Our group obtained wide-field mosaic data of the NGC 1333 star-forming region in the spectral lines N<sub>2</sub>H+(1-0), HCN(1-0), HCO+(1-0) and in  $\lambda$ =3mm continuum. CARMA's Python observing interface is flexible enough that only a small change was required to simultaneously obtain the "zero-spacing" data by standard ON-OFF position-switching as part of the mosaicking process. These data were then used to recover spatial frequency information resolved out by the interferometer.

### 3. Workflow

The foundation provided by MIS allowed us to establish a fairly simple workflow for new data as they were obtained, enabling the team to quickly assess the situation before the next observing run.

1. Download new data from CARMA Archive (essentially wget). Each dataset is between 200 and 900 MB.
2. Inspect and Flag bad data
  - Two people separately inspected the data, and flagged any considered bad. They then compared their flag choices and agreed on final flags for that day's data.
  - The final flagging selection was save in a MIRIAD-friendly flagging definition file and checked into CVS. All cross-correlation flags apply also to auto-correlation data.
  - Reasons for flagging were posted along with any other data reduction notes to the project wiki.
3. Derive standard interferometric calibrations (passband, phase, amplitude).
4. Update uv-coverage and integration time maps. These were used to modify mosaic starting point for next run of observing script in order to keep these quantities as uniform across the map.
5. Make interferometric and singledish maps for current data.
6. Make interferometric and singledish maps using all data so far.

### 4. Example Scripts

This procedure was encoded in the follow way, using Unix shell scripting language:

```
# grab copy of the data
piperun n1333.lis      'getdata link=1'

# process SD
piperun n1333sd.lis    do_uvcatSD flag=1
piperun n1333sd.lis    do_reduceSD device=/null sleep=0
```

```
piperun n1333sd.lis    do_mapSD device=/null
do_mapSDmedian4

# process INT
piperun n1333.lis      do_uvcat1 flag=1
piperun n1333.lis      do_inspect1
piperun n1333.lis      'do_cal1 calflux=12.5'
do_mos1

# joint deconvolution of SD and INT
do_jd
```

## 5. Example Results

Once all data for the project were obtained, the interferometric and singledish data were combined in a joint deconvolution technique (see e.g. Stanimirovic et al. (2002)) to create maps that contain all spatial scales. Figure 1 shows the HCO+, HCN, and N<sub>2</sub>H<sup>+</sup> integrated intensity maps resulting from the joint deconvolution.

At the start of the pipeline the raw data amounted to about 16 GB, growing to about 60 GB when all data have been processed into one continuum and 3 datacubes (for each molecule) of about 700 x 900 x 150 pixels.

**Acknowledgments.** We like to thank our N1333 team members Lee Mundy, Maxime Rizzo, Demerese Salter, and Shaye Storm.

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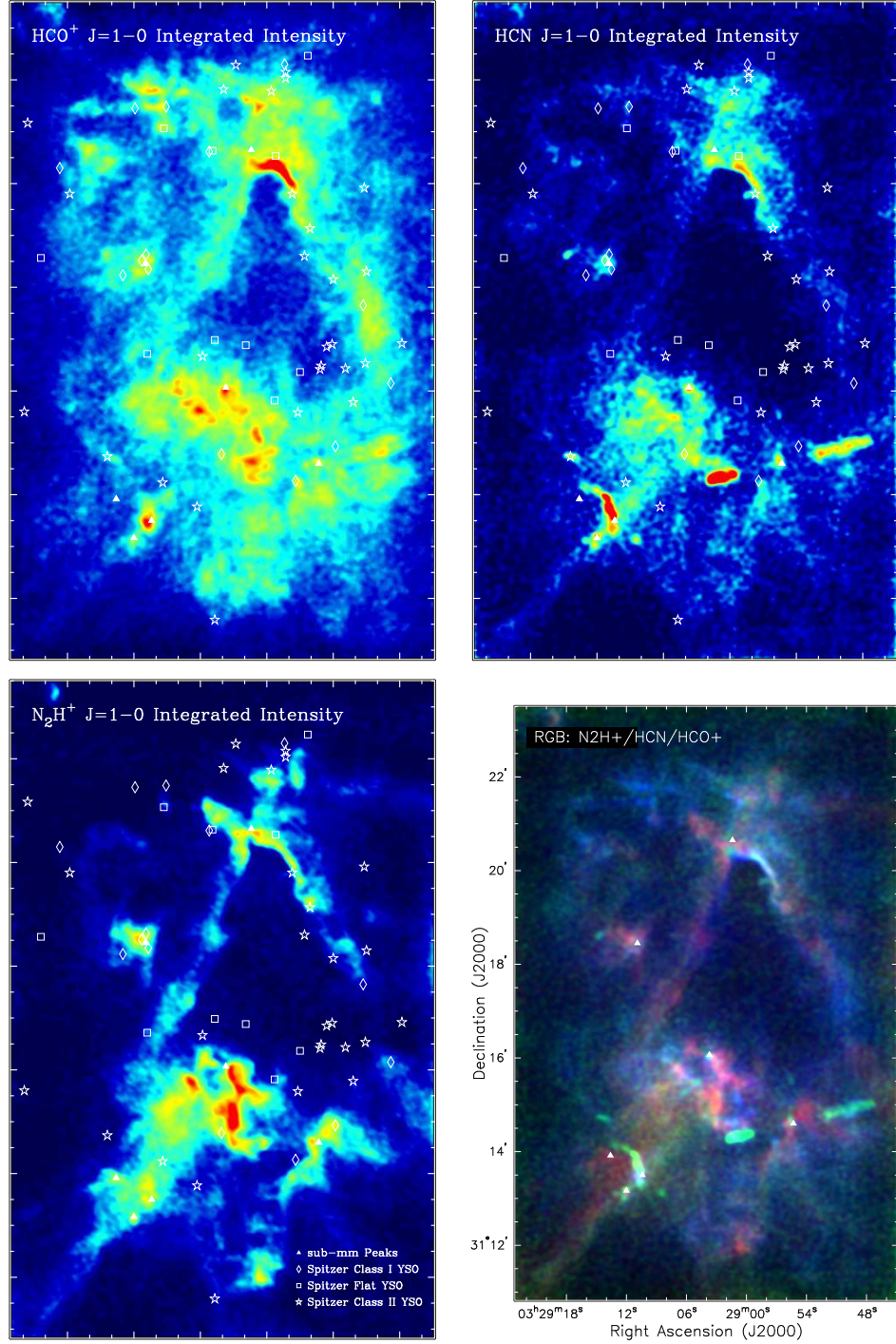


Figure 1. Integrated intensity maps in the three molecular lines covered by the CARMA survey. Top left:  $\text{HCO}^+(1-0)$ ; top right:  $\text{HCN}(1-0)$ ; bottom left:  $\text{N}_2\text{H}^+(1-0)$ ; bottom right: Combined RGB image of the three molecular line maps, showing the features highlighted by the different tracers. For instance, the protostellar outflows from IRAS2 and IRAS4 are evident in HCN (green).